1887MNRAS..47..309G

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. XLVII. APRIL 6, 1887 No. 6

EDWIN DUNKIN, F.R.S., Vice-President, in the Chair.

The Rev. John Bone, St. Thomas's Vicarage, Lancaster;

W. F. Caborne, Lieut. R.N.R., F.R.G.S., F.R.Met.Soc., 4 Cambridge Gardens, Notting Hill, and Royal Navy Club, Grafton Street, W.;

Campbell M. W. Hepworth, Lieut. R.N.R., 60 Matlock Lane, Ealing Dean; and

William Frederick Smith, F.R.Hist.Soc., 51 Perham Road, West Kensington, S.W.,

were balloted for and duly elected Fellows of the Society.

On the Choice of Instruments for Stellar Photography.

By Howard Grubb, F.R.S.

In view of the Astronomical Congress about to be held in Paris, the subject matter of its deliberations, viz. stellar photography, is naturally attracting much attention at present among astronomers; and I venture to hope that a few notes which I have put together on this subject may not be without interest to the Fellows of the Society. At the same time I desire to premise that I submit them, not with an idea that they possess any peculiar originality, but more as suggestions, and as tending to show the great number and diversity of points which will require to be thoroughly discussed before coming to a satisfactory conclusion as to the best instrumental equipment to satisfy all the conditions which arise in undertaking this new class of astronomical work.

1887MNRAS..47..309G

The first and most important question to be decided is whether a refracting or reflecting telescope is likely to give the best results. Theoretically considered, the reflector would appear to have a considerable advantage, for in it there is no *dispersing* of the rays. If the spherical aberration be properly corrected, *all the rays* are brought to the same focus; whereas in the refractor it is not so. If the curve formed by the foci of the different rays of the spectrum be examined, in the case of a refractor, it will be seen that with any possible combination of existing glasses, or arrangements of same, a very small portion only of the whole light can be brought to one focus on the photographic plate; again, the field of the reflector is theoretically flatter; but at the same time, as pointed out by Lieut.-Gen. Tennant at last meeting, a considerable amount of "coma" is to be found in lateral pencils of the reflector, which coma causes distortion of the star discs.

Generally, however, the advantage appears to be on the side of the reflector. It was for these reasons that, when consulted some time ago by Mr. Roberts of Liverpool, I advised his adoption of the reflector in preference to the refractor for photographic purposes.

The value of Lieut.-Gen. Tennant's papers would have been largely increased had he gone a little further, and shown what the *comparative* results would be for the lateral pencils of a refractor. Nor would this be at all impracticable; for, although the result may vary with different constructions of objectives, it would still have been interesting to study the effect on the one ordinary form of double objective (corrected, of course, for chemical rays) such as I have constructed for Dr. Gill, and such as is, I believe, also used by the MM. Henry. At the time I came to the above conclusion respecting the superiority of the reflector I had nothing to guide me but deductions from theoretical considerations. Since then, however, the work of the MM. Henry at Paris, and Dr. Gill at Cape-Town, with refractors, and Mr. Roberts at Liverpool, with a reflector, present some practical results from which to draw further deductions, and while I readily admit that the refractors have done better work than I had expected, I am by no means prepared to admit without further demonstration that under equal conditions they may be expected to do *better* work than the reflectors.

I have not myself had an opportunity of comparing the negatives taken by the reflector and refractor; but I understand from those who have that while the star discs in Roberts' (reflector) photographs show in all parts a slight want of symmetry, there is no decided elongation of the discs up to 80′ from centre of field, whilst in the refractor photographs there is a decided distortion at that distance. The want of perfect symmetry in Roberts' photographs is probably due to the fact that the power of his finder, as compared to the main telescope, is not nearly so great as is used in the case of the refractor.

1887MNRAS..47..309G

No doubt Mr. Roberts has not produced the same number of equally fine plates as the MM. Henry; but when we wish to compare results with a view of drawing a comparison between the value of the instruments which have produced those results, it is right and just to take the best specimens of each (not the average), for the inferiority of any examples which are of an excellence less than the best must be attributed to some unfavourable conditions outside the instrument, not in it. An inferior instrument cannot, under any circumstances, give a good result; and Mr. Roberts' best specimens appear to me to compare very favourably with those done by the refractors.

In making the comparison due regard must be had to the fact that the atmosphere of Liverpool is of very inferior quality as compared to that of either Paris or Cape-Town, and also that Mr. Roberts' photographs show an enormously increased number of stars on account of the large aperture of his instrument; but that very large aperture requires of course a still greater degree of perfection of atmosphere in order that its full power may be utilised.*

I do not for a moment dispute the fact that most excellent results can be, and have been, produced by a refractor; but it appears to me that it would be very unwise to spend large sums of money in the installation of several large refractors over the world without some further and more crucial comparative experiments as to the relative fitness of refractor and reflector for this particular work. Mr. Roberts has certainly shown that most excellent work can be done with the reflector; but his instrument is not comparable with the refractors which have been at the same work either as regards size, position, or many other respects.

It is, no doubt, highly desirable that the important work of mapping the heavens should be commenced with as little delay as possible; but it would be equally regrettable if in the beginning a large amount were expended on instruments which proved after a little to be not *the very best* for the purpose. I would venture to suggest, therefore, that a really fair competitive trial be made between refractors and reflectors, to test their fitness for celestial photography, before any definite decision be arrived at. This need by no means impede or hamper the work of the Congress in deciding other questions which could be made dependent on the results of these trials, and six months would probably decide the question.

In the photographing of nebulæ there can be no doubt whatever as to the superiority of the reflector, for in this case increase of angular aperture means increase of light and reduction of exposure, and the angular aperture of reflectors can be increased far beyond what is possible in case of refractors.

---

* Since writing above I have received information, founded on practical results, which materially strengthens my views. Professor Pritchard has succeeded in producing photographs with the De la Rue reflector, in which the images at 80′ from centre are sensibly circular, while at same distance in MM. Henry's (refractor) plates the small star discs are ellipses, the proportion of whose major and minor axes are 9 to 4.

In connection with the optical portion of the instrument there are a great number of important points which it would be most desirable to discuss; and I mention some of these, not so much with a view of giving my own individual opinion about them, as in the hope of eliciting opinions from others, and having them fairly and fully discussed.

Effect of Increase of Actual Aperture.—Theoretically, so far as star discs are concerned, the brilliancy should increase as the square of the aperture. Long since, in discussing this with Dr. Huggins and Mr. Roberts (before I had any practical results to guide me), I stated that I thought it very likely that the increase of brilliancy would not be in such a high ratio; for practically the discs (of large stars at least) are not mathematical points. Practice, I think, has corroborated this view; but more details are required to make it quite clear.

Effect of Increase of Angular Aperture.—The actual aperture remaining the same, reduction of focus or increase of angular aperture ought *not* to increase the brilliancy of star discs; but, for the same reason as above, it would appear that it does so to some considerable extent.

This, however, is also a question that requires more experiments to enable us to come to a decision upon.

Field of View.—In a refracting telescope the field of view is limited simply by the amount that can be covered by the objective with sufficiently good definition.

In a reflector the conditions are much more complicated.

If the focus be made long the field is flatter and can be used larger; but, on the other hand, the photographic plate and carrier begin to stop out an inconveniently large portion from the centre of the pencil of light.

If the focus be shortened a smaller plate will take in the same angular quantity of field, but that field will not be so flat.

There appears, therefore, to be some proportion that will be found to be best.

So far as present results go, they tend to show that with either a refractor or reflector a field of about 2° × 2° is the maximum attainable with really good definition. Much larger fields may be obtained with combination of lenses; but these are useless for the purpose, as, the pencils not being *all* centrical, a certain amount of distortion is inevitable.

Silver-on-Glass or Metallic Mirrors to be used.—Silver-on-glass mirrors are now so universally used, and so convenient on account of their lightness, that it may seem almost useless to discuss this. However, if the very best result is aimed at, I am inclined to think it might be well to institute some experiments to test the relative reflective powers of speculum-metal and silver for those rays which are used for forming the image on the photographic plate. There are good grounds for supposing that

1887MNRAS..47..309G

speculum-metal is more highly reflective for chemical rays than silver.

Long since I obtained photographs of the Moon with the Melbourne telescope, with exposure of from quarter to half a second, using the old collodion process and no peculiarly rapid process. Plates are now made 50 to 100 times as rapid as this old process, but I have never as yet heard of any photographs of the Moon having been taken with a silver-on-glass mirror in $\frac{1}{200}$th or $\frac{1}{400}$th of a second. An idea has been thrown out that the field of a reflector could be improved by modifying the figure of the mirror. This is quite impracticable, as any modification whatever would affect the definition of the central pencil.

It has been objected to reflectors that the film or surface is liable to tarnish, and therefore these instruments are not so stable, and are therefore less suited for long-continued observations.

Metallic mirrors, if the metal is good, I believe to be almost as stable as an object-glass; but even if not so, this is a point of little consequence, for Mr. Roberts tells me that under apparently equal conditions of atmosphere he sometimes obtains three times the number of stars in the same locality as at other times.

With such an enormously variable factor as this to deal with, a slight variation in the condition of the film is of little account.

Best Size of Instrument to adopt.—The larger the instrument the shorter the exposure necessary to obtain an image of a star of any given magnitude; but the difference in this respect will probably not (as I have before said) be on as high a ratio as the theoretical—viz. square of aperture.

On the other hand, the larger the instrument the more difficult will it be to find a night sufficiently good to use it advantageously.

The question of size is therefore mixed up with many others, such as geographical position, accuracy of clockwork, minimum magnitude of star desired to be mapped, rapidity of plates, &c.

In order to determine the best size of instrument it would be necessary to determine first the minimum magnitude of star it is desired to photograph; secondly, for what time the clockwork could be depended upon to go sufficiently accurately to preserve the symmetry of the image.

The problem would then resolve itself into this: What is the *least* size of telescope which would photograph that particular magnitude of stars in that particular period with the quickest plates obtainable?

General Form of the Equatorial Mounting.—If a reflector be used, and more especially if the mirror be metallic, the ordinary so-called German form of equatorial, slightly modified so as to give circumpolar motion, will fulfil all necessary conditions; but in case of a refractor it has been suggested that the old English split polar axis might be more convenient.

1887MNRAS..47..309G

In ordinary eye and micrometrical observations the necessity which exists in all equatorials of the German form of reversal is not any great inconvenience, but in stellar photography absolute circumpolar motion is almost a necessity.

It would not be possible to stop during the exposure of a plate, reverse the telescope. and commence again at the other side. It is possible to make the German form circumpolar in this latitude up to the zenith; but to do so for refractors beyond that involves a construction somewhat of the form of Colonel Tomline's, which is clearly impracticable for instruments which have to be transported.

With a reflector, however, the whole telescope being short, the lower end being short in case of a metallic mirror, and the person of the observer being at the upper end, it is perfectly practicable to make the German form circumpolar—at least for these, and even a lower latitude.

Effect of Refraction.—It is very important to study the effect of refraction in disturbing the position of the images; for if, as has been stated, the effect is so great that even in favourable altitudes and with a perfect clock a hand correction must be made every two or three minutes, it would appear almost useless to go to very much trouble about the clock, at least in controlling it so as to keep its rate correct for long periods.

Dr. Dreyer of Armagh has kindly made some calculations for me respecting the effect of refraction. I have only just received his calculations as I send this paper to the printers; but the results are so interesting that they appear worthy of further investigation.

Taking a star near the equator and on the meridian, the difference in Declination for short periods is very small. I have assumed that a shift of star image in plate of 0″·5 would be the least that could sensibly affect the symmetry of image. That 0″·5 error would not occur in Declination for nearly half an hour; but in Right Ascension the error would amount to this quantity in two minutes. The curious part, however, is that this difference in Right Ascension is nearly constant for a considerable distance from meridian: thus, one hour off meridian it is still about 0″·5 in two minutes, and nearly the same at two hours off meridian.

The practical deductions to be drawn from this are :—

(1) That a really perfect controlled clock can be fully utilised, even for long periods, and that it is highly desirable to have such;

(2) That this clock should be provided with an arrangement for introducing very slight changes in its rate.

Clockwork.—This is of course the most important of all the details of an equatorial intended to be devoted to stellar photography.

There are many uniform motion clocks which go smoothly and uniformly for short periods; but for long periods it is abso-

1887MNRAS..47..309G

FIG. 1.

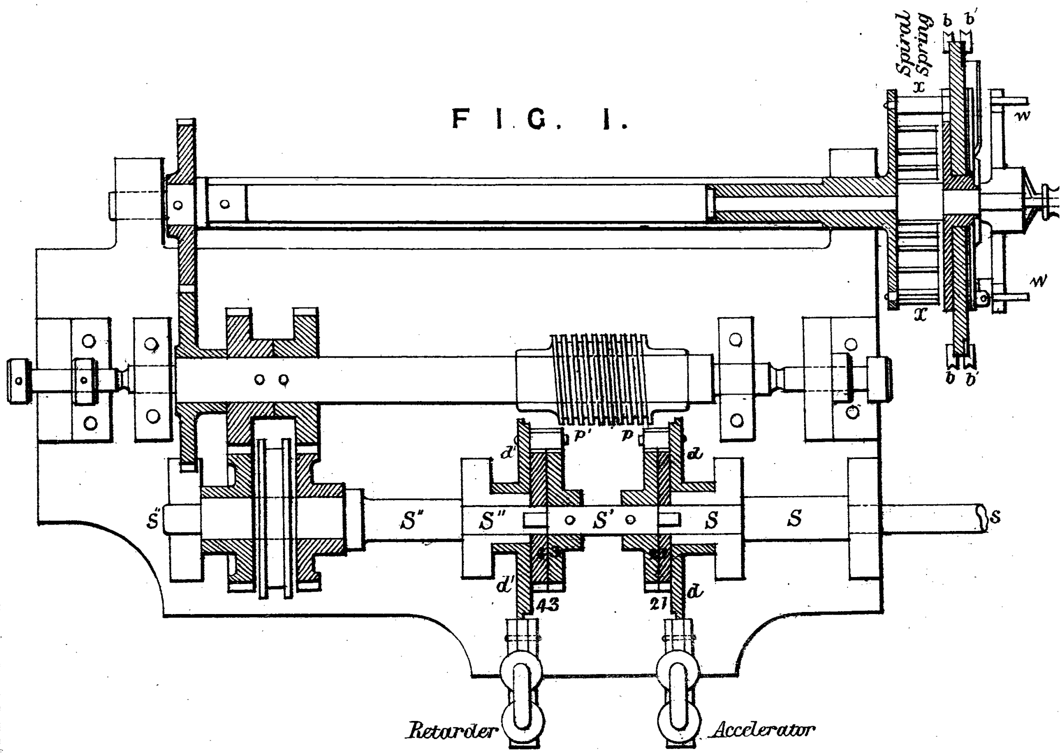


FIG. 2.

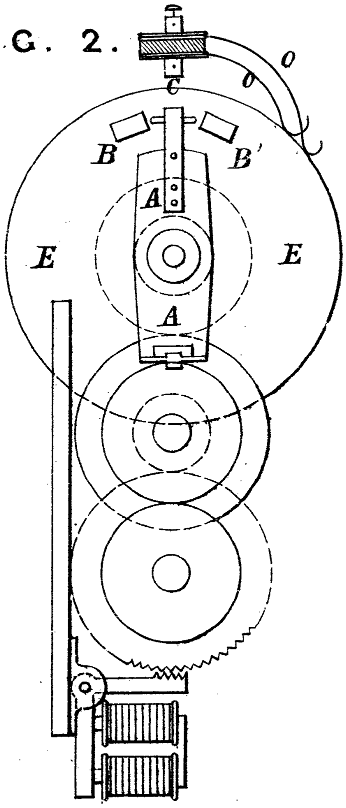
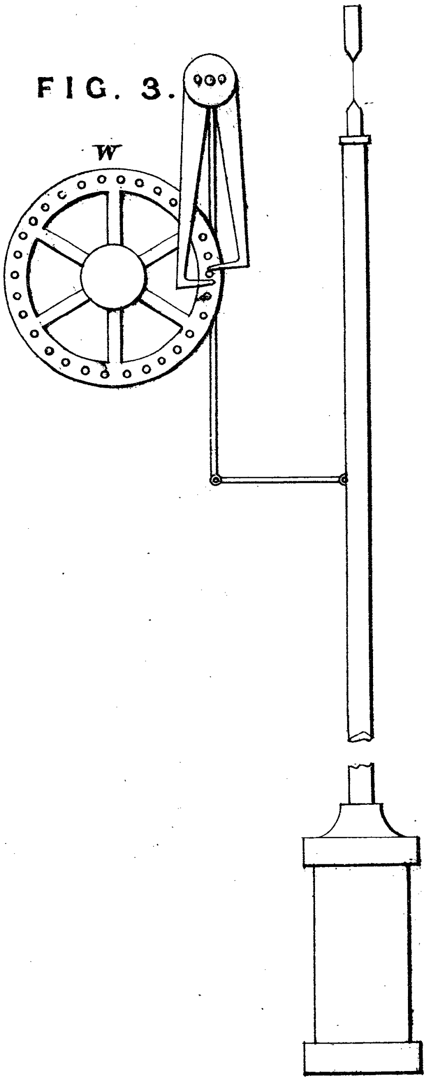


FIG. 3.



1887MNRAS..47..309G

lutely necessary to have some controlling action from a pendulum. The form of control which I have found best consists of two parts—

(1) A detector apparatus for detecting the errors of equatorial clock, using as a standard a mercury or other good pendulum driven by a *remontoire*, so as to be uninfluenced by the incorrect rate of the equatorial clock.

(2) A correcting apparatus for correcting any errors found in the equatorial clock by the detector. This corrector itself naturally consists of two parts—an "accelerator" and a "retarder."

It will be necessary to describe first this accelerator and retarder.

Any of the clock-shafts between the clock and the endless screw which drives the Right Ascension sector is cut into three pieces—Plate 4, fig. 1—S, S′, and S″.

On the end of the shaft S is fixed the wheel 1. On the end of the shaft S′, next S, is fixed the wheel 2, close up to and almost touching 1.

On the other end of shaft S′ is fixed the wheel 3, and on nearest end of shaft S″ the wheel 4. Also, on the shafts S and S″ are placed discs of brass, *d* and *d′*, close to the pair of wheels 1-2 and 3-4; but these discs are *free to turn on shafts.*

On a stud on these discs are pinions, *p* and *p′*, which gear across both wheels of each pair, *p* gearing across Nos. 1 and 2, *p′* across Nos. 3 and 4. In general the whole of this apparatus revolves together and as one piece; but it is possible during the action to arrest the motion of one or other of discs *d* and *d′*, which causes the pinion to revolve on its own axis, and the motion is transmitted to the adjacent wheel through the pinion. If the two adjacent wheels have exactly the same number of teeth the speed remains the same; but if one wheel has (say) one tooth more than the other, a slight difference in speed takes place between the driving part and the driven part of the spindle. For example:

Suppose wheel 1 to have 30 teeth and wheel 2 to have 29 teeth, and that spindle S be revolving at the rate of once in 60 seconds. If now the motion of disc *d* be stopped, the wheel No. 2 and its spindle S′ will be revolving once in 58 seconds instead of once in 60 seconds. By reversing the position of the wheels at the other end of spindle S′ a retardation occurs on stopping its disc *d′*.

If, therefore, the normal rate of spindle S, S′, and S″ be once in 60 seconds, a stopping of disc *d* will cause screw to revolve (as long as disc *d* is held) once in 58 seconds, while a stopping of disc *d′* will cause same to revolve once in 62 seconds.

This stopping is actually accomplished by cutting the edge into a set of very fine teeth (see fig. 2) into which a comb or

1887MNRAS..47..309G

the armature of an electro-magnet engages. When therefore a current is sent through the magnet of the accelerator the screw is accelerated $\frac{1}{30}$th part, and when sent through the magnet of retarder the screw is retarded $\frac{1}{30}$th part.

To understand how these currents are sent from the detector, see figs. 2 and 3.

A scape-wheel, W, is mounted on a 60-second spindle of clock, and driven from that spindle by a spiral spring x x, fig. 1, so that no error of equatorial clock can affect its rate or the rate of the pendulum. On same clock-spindle behind scape-wheel is mounted an ebonite disc, E E, fig. 2, on which are fixed two brass insulated rings, b b, fig. 1, connected metallically with two platinum plates B B′, inserted in face of ebonite disc E E.

Between scape-wheel and ebonite disc is an arm, A A, also mounted on spindle and loose on it, having at its end a little platinum bridge C, of such a length as to fit between the two platinum plates B and B′.

The ebonite disc moves uniformly with the equatorial clock.

The scape-wheel works absolutely correctly with the pendulum and is uninfluenced by error in clock.

The arm A A moves by friction from the ebonite disc, and remains with its bridge exactly between the two platinum discs B and B′ so long as the rate of clock is exactly coincident with the rate of scape-wheel; but if the clock goes the least faster or slower, a pin on the scape-wheel touches arm A, moves bridge C into contact with B or B′, and sends a current through the accelerator or retarder until that error be corrected.

A piece of rock-crystal is inserted between the two pieces of platinum for the bridge to slide on.

The current is guided to brass rings b b' by the fine platinum wires o o', which wipe against them.

The time which the accelerator or retarder is kept in action depends on the amount of error it is necessary to correct.

Assuming the proportions given above for teeth of wheels, and that an error—of, say, $\frac{1}{5}$th of a second—is by some means introduced, the corrector will be held in contact for 6 seconds, because for every revolution it is held in contact (that is, for every 60 seconds) a correction of 2 seconds will be made, so 6 seconds' contact will correct $\frac{1}{5}$th of a second.

The advantages of this control are—

(1) It not only brings the rate of the clock right after any temporary disturbance, but it *corrects* any errors that may have already occurred. This is absolutely necessary for photographic work, as otherwise the star would occupy a new position on the plate though rate of clock were corrected. [N.B.—all ordinary forms of fan, frictional governor, isochronous pendulum, &c., only tend to correct the *rate* of the clock, but do not deal with any error already existing.]

1887MNRAS..47..309G

(2) The detector arrangement, being attached close to screw-spindle, takes cognisance of all the errors of the various spindles and wheels between clock and screw as well as clock itself.

(3) It is more smooth and equable in its action than any other form, for instead of endeavouring to alter the rate of a heavy moving governor *it allows it to go wrong*; but introduces a corrective arrangement into the gearing so as to *compel the screw* to revolve exactly correctly.

The practical result of this control-clock I find to be that it is admirable for long periods; but the delicacy of the detector part is not as great as I could desire.

Owing to the fact that the linear measure of a second of time on the detector disc (revolving once in 60 seconds) is a small quantity, I find that practically the detector will not detect errors less than $\frac{1}{5}$th to $\frac{1}{10}$th of a second; but it will keep the clock right within *that* error for any number of hours. In other words, the correcting portion of the apparatus (the accelerator and retarder) work perfectly, but the detector is not quite delicate enough. I think it likely that a combination of Dr. Gill's detector (that used at Dun Echt) and my corrector would give the most perfect clock-control possible.

I prefer my corrector because it takes into its influence all the errors of the various connecting shafts, &c., between clock and sector, which Dr. Gill's does not.

Dr. Gill has suggested, in order to avoid all unnecessary wheels and gearing between governors and screw, that the governor spindle should have an endless screw cut on it, gearing *directly* into a toothed wheel on screw-spindle, and that this governor should be driven by a small electric motor and governed from the control by a variable resistance apparatus. The first part of this I consider a most admirable suggestion; but instead of driving by electricity and regulating by the varying resistance, I would still drive by a weight and introduce the correction by my accelerator and retarder, which I find to work so well.

There are many reasons for which I prefer this to the electric driving, among which are:—

(*a*) That whenever possible I prefer gravity (which never fails us) to batteries, as a motive power.

(*b*) That when we apply a corrector which necessitates the alteration of speed of a heavy and quick-moving mass (such as the governor) we are apt to set up a slight swing in the motion. The accelerator and retarder above described are free from that defect.

(*c*) If we adopt the electric driver, the control would have to correct all the errors due to want of constancy of

1887MNRAS..47..309G

> the battery as well as the mechanical errors of the clock, and as the former would probably amount to 20 per cent. of the whole, while the latter need not exceed $\frac{1}{3}$rd per cent., it is evident that $\frac{59}{60}$ths of the work of the control would be used in correcting a factor (the driving power) which, by adopting gravity, we render practically constant.

The form, therefore, of clockwork I would recommend as probably the best at present possible would be one driven by a weight, the governor gearing directly into a wheel or screw shaft. A *detector* similar to Dr. Gill's at Dun Echt, but driven, not from clock, but directly from screw-spindle, with only one pair of wheels intervening, and a pair of *correctors* on the principle of my accelerator and retarder.

Slow Motion of Equatorial.—For stellar photography it is absolutely necessary to have a slow motion of far greater delicacy and precision than that which suffices for micrometrical work. If in micrometrical work a slight turn of the handle to bring the star central causes the telescope to oscillate very slightly it is of no consequence, as the eye can wait till the oscillation subsides (I am speaking, of course, of extremely small quantities); but in an instrument for stellar photography this is not admissible, as it would cause the star disc to be elongated. Special arrangements, therefore, must be made for the slow motion in the photographic telescope.

Slow Motion in Right Ascension.—For this purpose (beside the ordinary slow motion used to bring star to centre of field) I find the best arrangement is to have another accelerator and retarder, similar to those described above for clock control, and to have the electro-magnets of these connected to a little commutator with two keys held in the hand of the observer. By pressing one the clock-spindle is caused to revolve $\frac{1}{30}$th part faster, and continues at this faster speed so long as the key is held down. By pressing the other a corresponding retardation occurs.

By using this arrangement there is no possibility of causing any jerk or sudden movement in the instrument. The key is held in the hand and is totally independent of the instrument. Pressing the key simply causes the screw to revolve $\frac{1}{30}$th part faster or slower for the time being.

Slow Motion in Declination.—I would be glad if possible to have an equally perfect arrangement for the Declination slow motion; but I do not see how this can be accomplished; and, fortunately, it is not quite so important as it is not so often in use. I incline to think that the German form of slow motion—i.e. a fine screw acting against a stiff spring—would be the best form, only that the strength of the spring is not constant, and, unless made very stiff, does not work well. I have introduced a modification of this which removes these objections.

A B C D (fig. 4) is a portion of the arm attached to telescope

1887MNRAS..47..309G

or cradle, on which is planted the block (*b*) forming the bearing of the screw. The nut (*n*) is in the form of a ball, working in a socket on the extremity of the clamp-arm E F G. A short stiff spring (S) is attached to this clamp-arm, bearing not directly against any part of other arm, but against end of a *second screw of same pitch as the main screw*, the nut of which (*o o*) is toothed on edge and works into a wheel of equal size (*p p*) on main screw. The point of this second screw, therefore, advances as much in one direction as the frame A B C D is carried in the other, according as the milled head is turned; and consequently the point of the screw does not sensibly vary in its position with respect to the clamp-arm E F G. A short stiff spring can therefore be used, and the disadvantage above mentioned disappears.

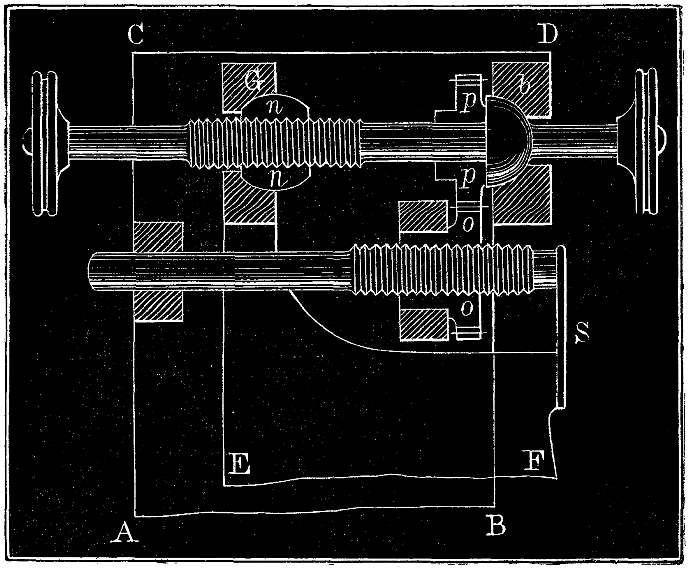


Fig. 4.

The most serious difficulty in using reflectors appears to be that of the want of constancy of the axis of collimation. A mirror cannot be fixed into its cell with the same rigidity as is possible in case of an object-glass, and if the smallest shift occurs during the exposure, any attempt to make the clock drive correctly or to keep a star on cross-line of finder by laborious eye observations are utterly futile.

The shorter the exposure, of course, the less danger of any shift during an exposure; but some system must be devised by which the axis of the finder can be kept in a constant position—not as regards the tube or mechanical fixtures of the reflector, but as respects its true optical axis.

This is not a very simple problem, but I feel quite sure that it is quite capable of being solved.

The necessity of its solution did not arise till now, and therefore no attention has been given to it.

1887MNRAS..47..309G

Let it be remembered that we have three possible sources of error—

(1) Lateral shift of mirror, i.e. sliding bodily on its supports.
(2) Flexure of tube.
(3) Tilting of mirror.

By giving the back of the mirror a convex curve equal in radius to concave at front + thickness of disc, the lateral shift has no effect on the collimation. The other two, however, have a very serious effect. An arrangement such as the following would take into account the error in collimation produced by either or both these.

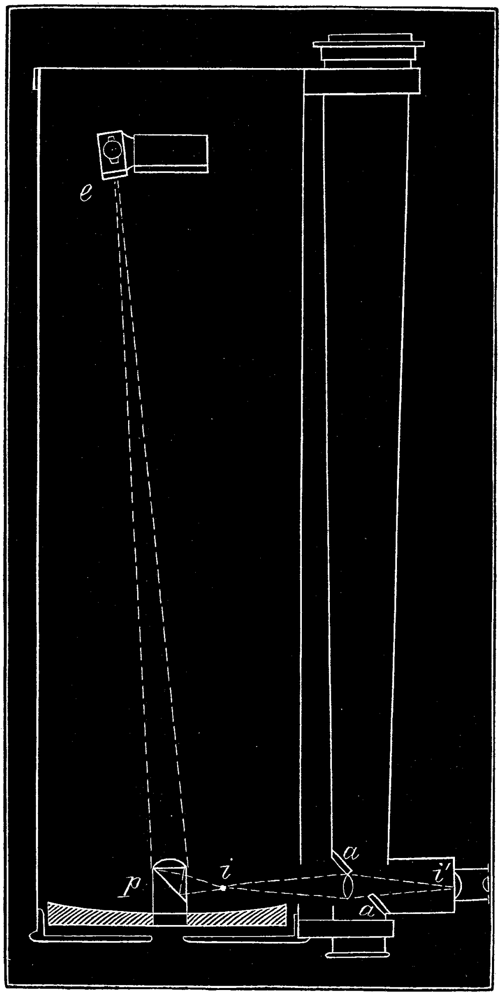


Fig. 5.

Beside, and a little behind, the photographic plate, *but attached* to same supports, let there be a small electric lamp, *e*, enclosed in a little box, and having in front a silvered glass window on which is scratched a minute circle. Let a prism and lens, *p*, be mounted

1887MNRAS..47..309G

on large mirror itself, in such position as to form an image of that little illuminated circle at i. Let the finder telescope be provided near eye-end with a diagonal mirror, $a\,a$, having a hole in centre, so that the image is thrown out to side of its tube at i; and let a lens be mounted in centre hole of that mirror, which will re-form the image of circle at i'. On looking into field of finder a ghost image of this circle will be seen in field, and the position of this ghost in field of finder will be affected by flexure of the tube of great telescope or tilting of great mirror. Therefore, if instead of keeping any certain star on fixed cross-lines of finder it be kept in *centre of this ghost ring*, the optical axes of finder and reflector will be kept constant, and the image on photo-plate will be absolutely steady, provided any star in field of finder be kept constantly in centre of that ghost circle.

It is quite possible that a better arrangement than this will be devised; but I mention the first that occurs to me in order to show that it is at least possible.*

Curved Plates.—It appears quite possible that the adoption of slightly curved plates might add considerably to the possible amount of field to be photographed with sufficient sharpness.

The curvature necessary to place the lateral portions of the plate in the place of least confusion would be very slight. In the case, say, of a reflector of 10 feet focus and for a field of 2° the versed sine of this curve would only be about $\frac{1}{60}$th of an inch.

There could be no manipulatory difficulties in coating a plate of this curve, for the common plates in ordinary use by photographers have often more curvature (accidentally) than this.

There would be no danger of any distortion occurring in reducing the observations from these plates if proper precautions were taken, and any extra expense of plates would be more than compensated for if even $\frac{1}{2}$° of additional field could be obtained with the same distinctness.

Many other points beside those above mentioned will have to be considered and discussed before it is possible to come to a definite conclusion as to the best instrumental equipment for stellar photography; but the object of this paper will have been attained if I have succeeded in showing that the subject is one in which new and unexpected conditions are continually presented for our consideration; and, that while we know enough now to be able to say that a certain instrument will give a good result, we really have not as yet sufficient data to enable us to say what will be likely to give the *best* result. For instance, the different conditions, instrumental and otherwise, under which Mr. Roberts and the MM. Henry have been working preclude any idea of drawing a decisive conclusion from a comparison of their results.

It appears to me that the most useful work the Paris Congress

---

* It may be observed that fig. 5 is only a diagram, and that the comparative size of the various parts of this collimating apparatus, as compared to telescope, are very much exaggerated for clearness' sake.

1887MNRAS..47..309G

could do would be to formulate a series of experiments which would clear up all debatable points. Arrangements might also be made to enable the work to be carried on immediately after these experiments were completed, the general features of the instrumental equipment to be contingent upon the result of the experiments. If it be possible for me to take advantage of the kind invitation of the French Astronomers, this is the view which I propose to put forward at the Congress.

Remarks on some of the present Aspects of Celestial Photography.

By Professor C. Pritchard, D.D., F.R.S.

When a new science, or a new application of an old one, is in the early stages of its development, as is now the case with stellar photography, any practical remarks connected with its history and progress will certainly possess a peculiar interest when, in the distant future, the art shall have been brought to comparative perfection. It is under this view that I venture to occupy for a few minutes the attention of the Society.

We are greatly indebted to General Tennant for his recent contribution to our theoretical knowledge of the nature and position of the foci of cylindrical pencils of light incident on parabolic mirrors, when the axes of these pencils are inclined to each other at considerable angles. By considerable angles I mean such as extend through one to three, or even four, degrees. These investigations have a very close and important bearing on questions relating to the angular extent of the photographic pictures of the heavens, which may be hoped for through the instrumentality of reflecting telescopes. One result which I gather from General Tennant's labour is that, even at angles slightly exceeding one degree from the axis of the mirror, discernible astigmatism and distortion may be expected to commence; and if such be found to be the actual result in practice, then photographic pictures of the distribution of stars will be necessarily confined within very narrow limits indeed; and if the whole heavens are to be photographically charted, then the number of the plates will become unavoidably enormous, inasmuch as no single plate could be expected to contain more than five or six square degrees, in at all events such perfection as not to offend the eye, and remind it forcibly and continuously of the comparative imperfection of the means adopted for the formation of the pictures. Passing for a moment from these inauspicious expectations of aid from telescopic mirrors, I find from a recent printed note of Mr. Common that the photographic results, at present derived from specially constructed object-glasses, are, in respect of accuracy of form and extent of available field, not much more hopeful than those predicted by mathematical in-